Cypress Pine Modelling Project

Interim Report Number 4, 1985

Seasonal Growth Pattern of Cypress Pine

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Abstract

Analysis of monthly height and dendrometer measurements totaling more than 600 tree years reveals that:

- Height growth exhibits a period of dormancy during July to September;
- Diameter increment may accrue whenever favourable conditions are experienced; relative humidity appears to be a major controlling factor; and that
- Natural reversible changes in stem size due to moisture status may attain a magnitude equivalent to the annual increment of the stem.

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1. Introduction

Investigations and applications using tree growth information generally require the annual increment. This can be readily determined when a tree (or plot) is remeasured on the anniversary of the previous measure. However, when the time interval is not an exact multiple of one year, some interpolation is necessary to derive annual increment.

In southern Queensland, tree growth may be continuous throughout the year, or may exhibit a period of dormancy. To illustrate the effect of these differing growth patterns on estimates of annual increment, it is expedient to consider two simple examples. Figure 1 illustrates a tree which grows at a constant rate throughout the year. The tree represented in Figure 2 grows at a constant rate for nine months and is dormant for three months during July to August. The assumption of constant growth when not dormant is unrealistic, but is convenient for this example.

If the assumption of constant growth is applied to the tree of Figure 1, an unbiased estimate of annual increment is obtained. If however, the tree had a dormant period, considerable bias could result, depending upon how much of the dormant period occurred between measures. Figures 3 and 4 indicate the extent of the possible bias resulting from the incorrect assumption of growth pattern. This bias is significant, particularly when remeasurement occurred after a short interval, when bias may exceed 100%.

It is not only the length of the dormant period which influences the estimates of annual increment. Figure 5 illustrates the effect of failure to correctly detect the onset of dormancy by only one month.

In order to utilize data derived from other than strictly annual measurements, some information concerning the growth pattern of the species is required.

2. Data

In 1974 an experiment (163 Dalby) was established to observe the short term growth pattern of Cypress Pine. This experiment recorded:

- Monthly observations on heights of sixteen trees (5-15 cm dbh) located at SF 154 Western Creek (Figure 6) during July 1974 to January 1979.

Figure 1. Constant Growth

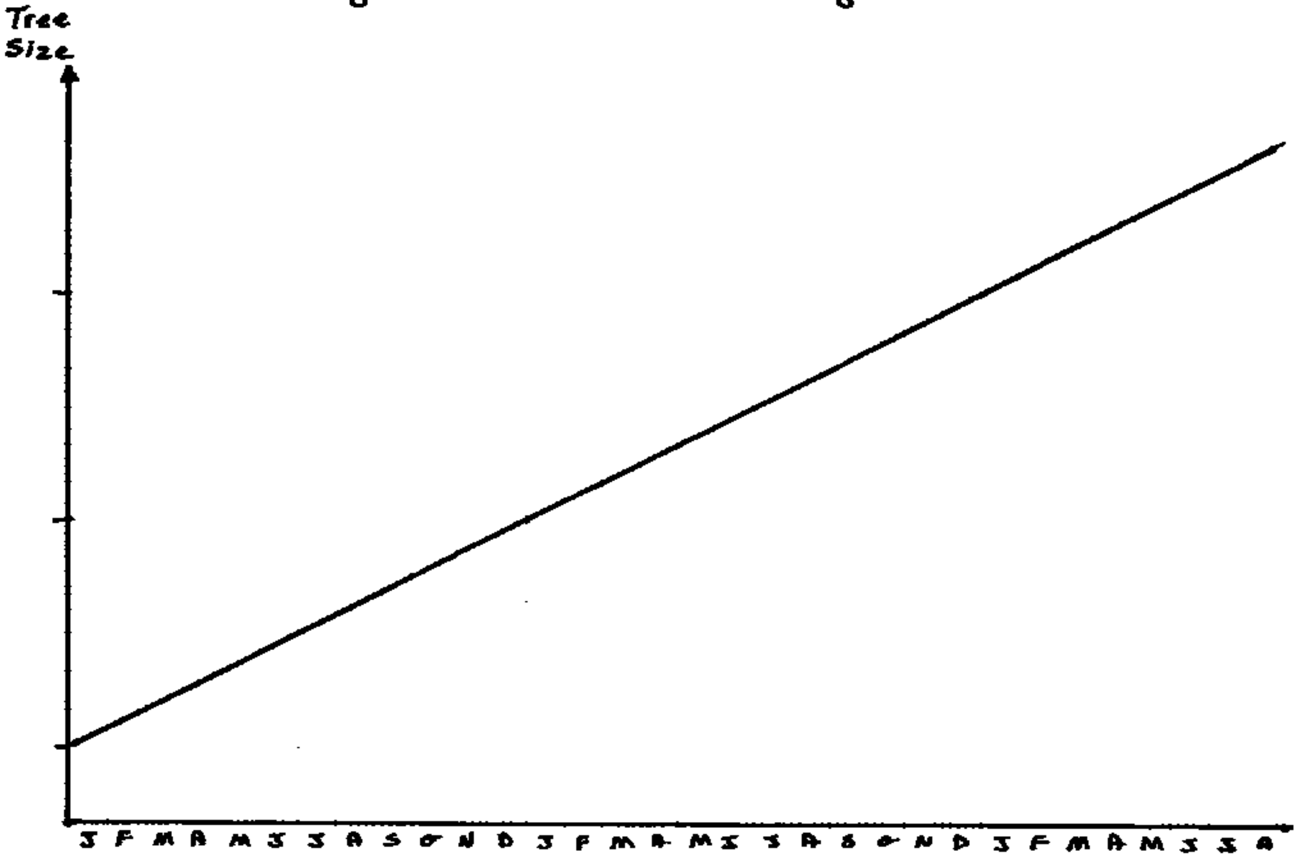


Figure 2. Three-month Dormancy

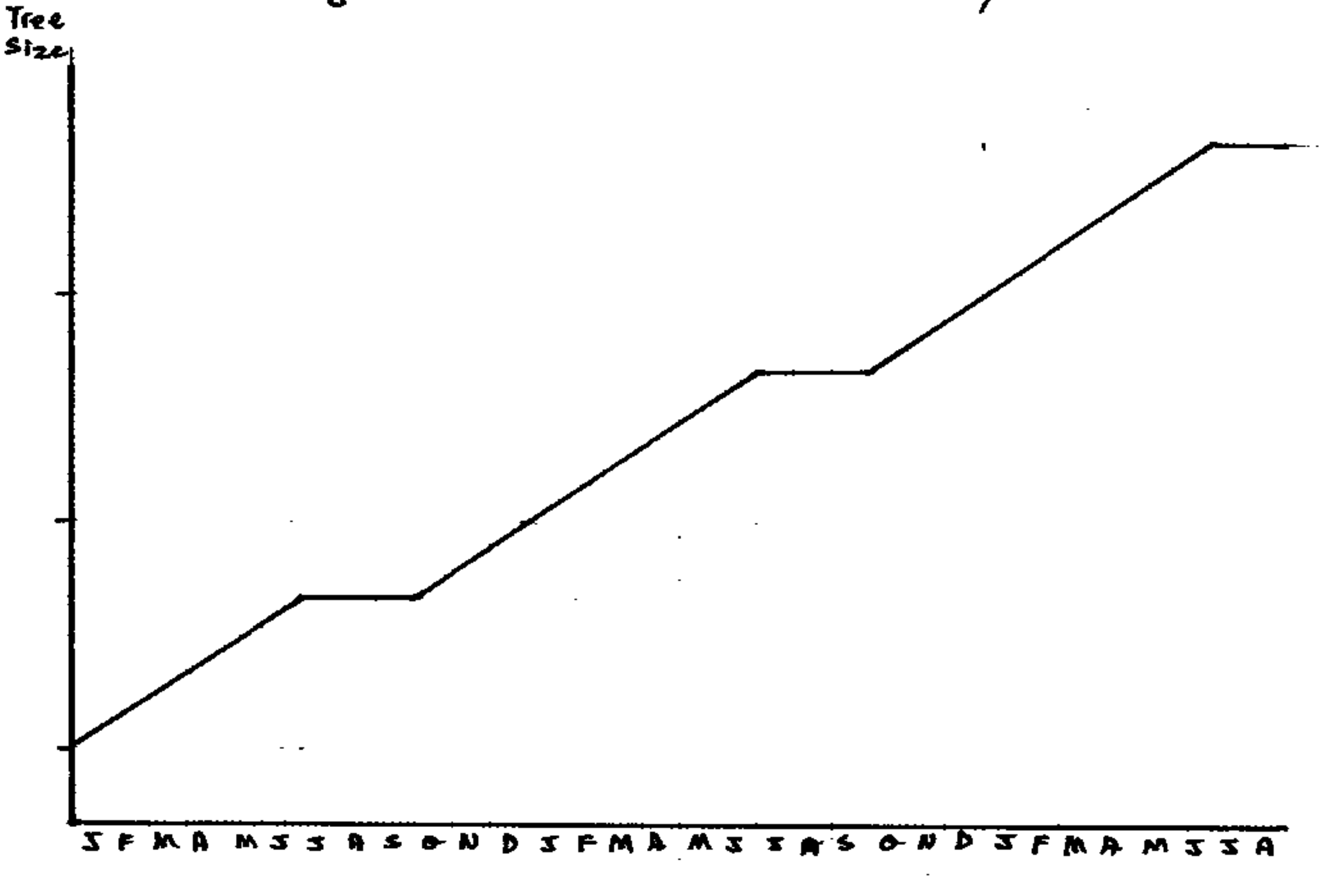


FIGURE 3. ASSUME CONSTANT GROWTH WHEN DORMANCY EXISTS

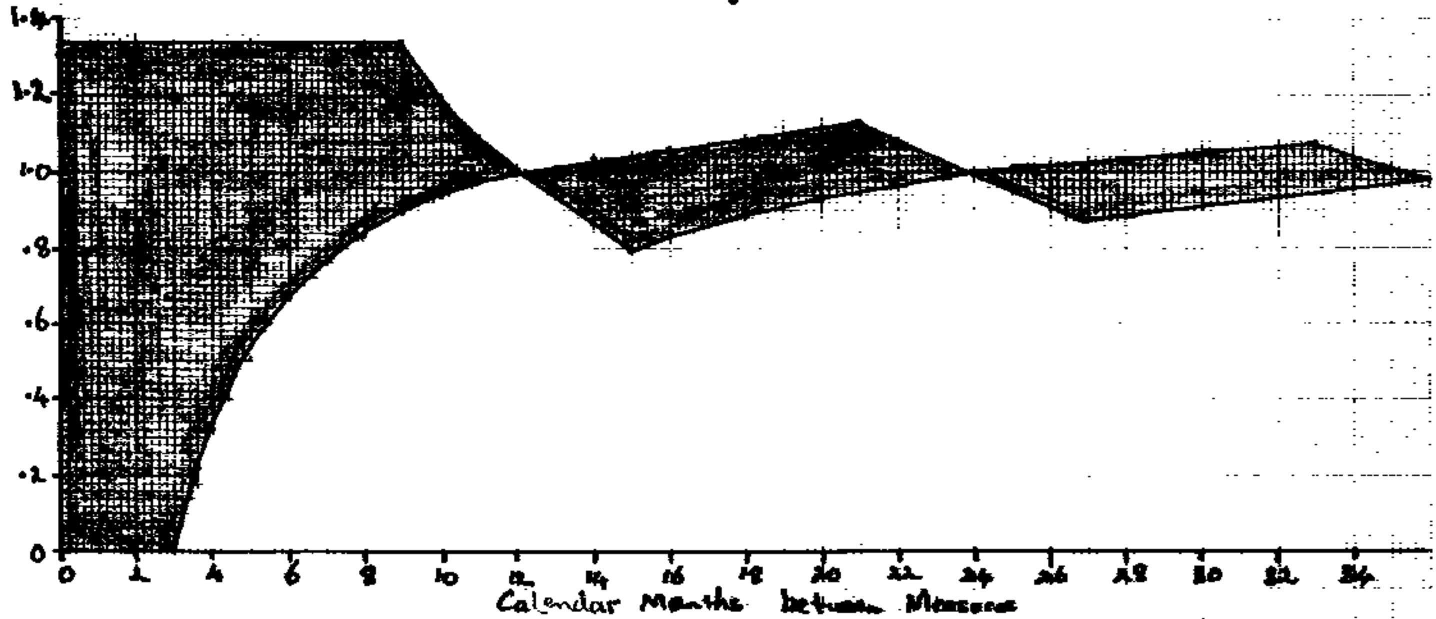


FIGURE 4. ASSUME DORMANCY WHEN CONSTANT GROWTH OCCURS

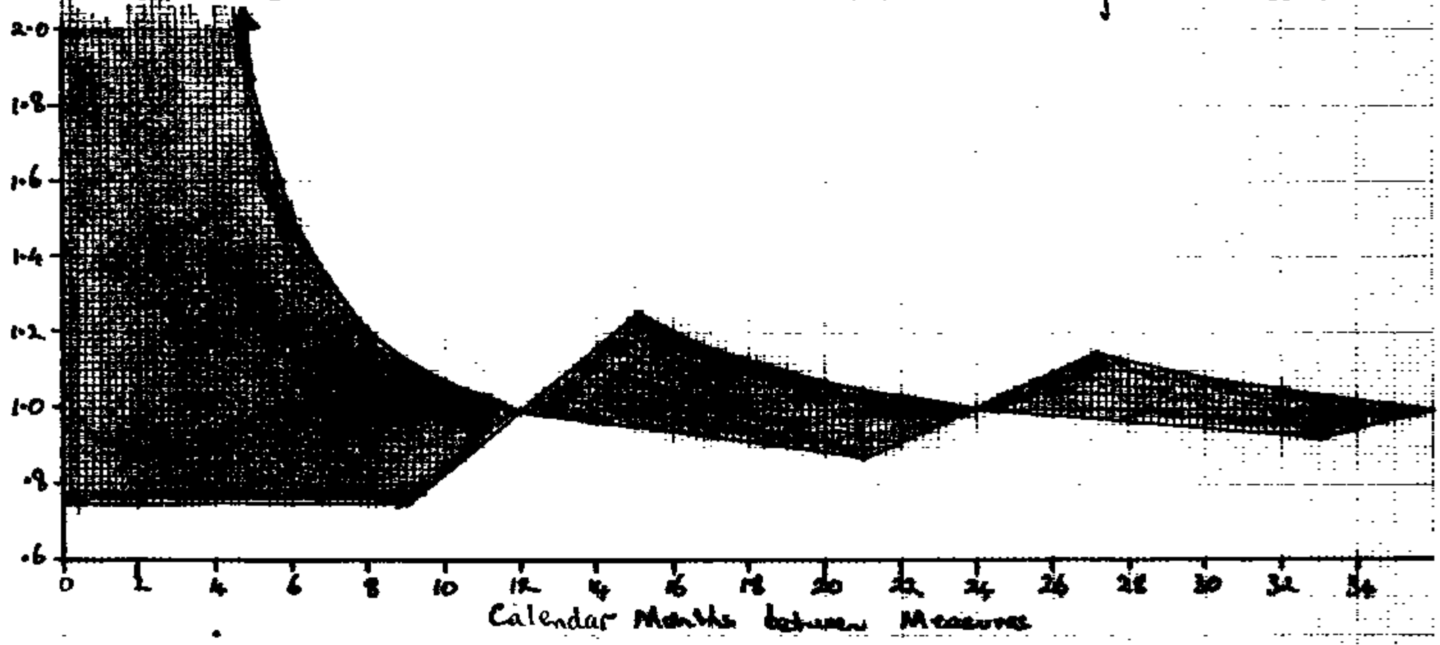
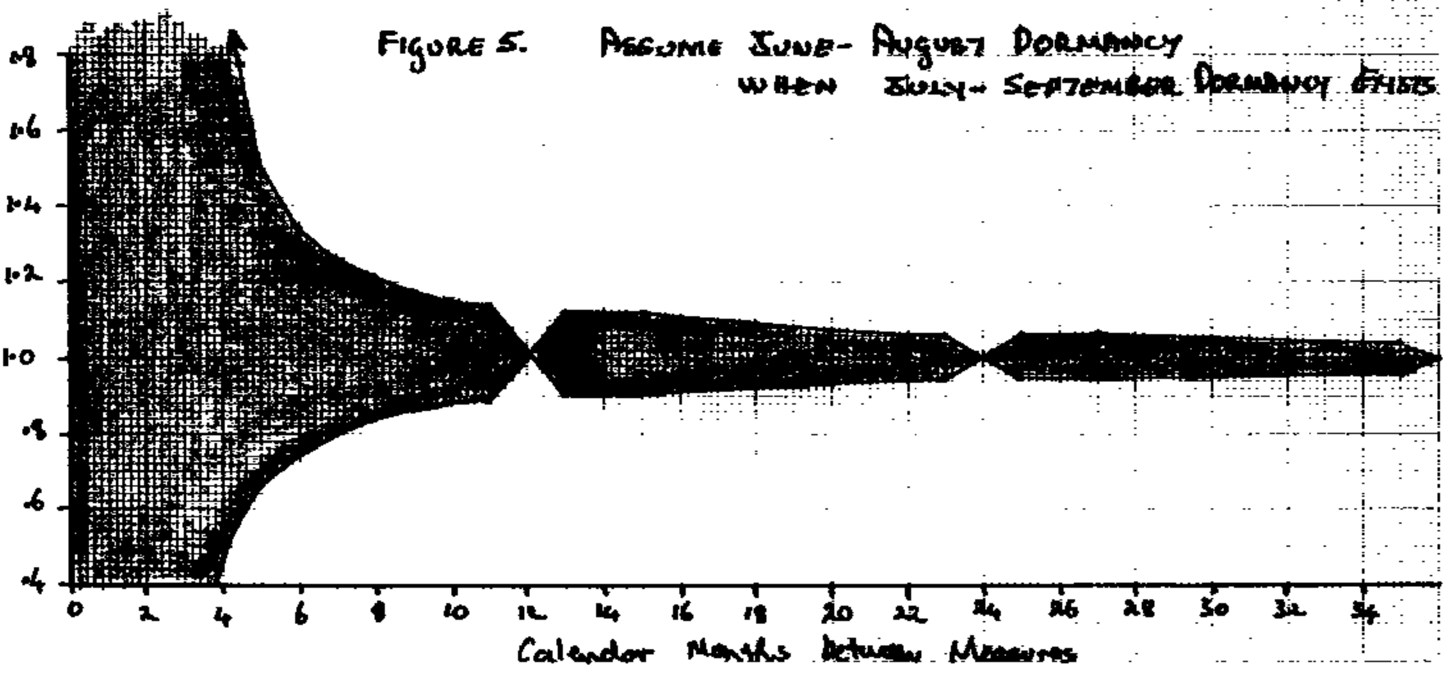


FIGURE 5. ASSUME JUNE-AUGUST DORMANCY WHEN JULY-SEPTEMBER DORMANCY EXISTS



POSSIBLE BIAS: PREDICTED/ACTUAL ANNUAL INCREMENT.

- Monthly observations on diameter of 168 trees at five different locations during July 1974 to January 1979. These included

  - ten trees each in 0-10, 10-20, 20-30 cm d.b.h. classes at SF 10 Hillside;
  - ten trees each in 5-15, 15-25, 25-35 cm d.b.h. classes at SF 55 Pony Hills;
  - ten trees each in 5-15, 15-25, 25-35 cm d.b.h. classes at SF 328 Yuleba;
  - ten trees each in 5-15, 15-25, 25-35 cm d.b.h. classes at SF 302 Barakula; and
  - sixteen trees each in 5-15, 15-25, 25-35 cm d.b.h. classes at SF 154 Western Creek.

- Daily observations on diameter of ten stems located near the Barakula (SF 302) camp during August 1975 to July 1976.

Diameters were measured using a graduated stainless steel dendrometer band (Liming 1957), permanently fitted to each tree, which enabled diameter to be recorded to the nearest 0.1 millimetre. Heights were measured to nearest centimetre using height sticks and a permanent reference peg driven firmly into the ground near the base of each tree.

Daily diameter observations were made at 9:00 am (also at 3:00 pm). Monthly diameter and height observations were made near the start of the month, at various times of the day.

Rain gauges installed at each location were read monthly at the time of diameter/height measurement, and paired gauges at the Barakula Office read daily and monthly enabled a comparison between monthly readings and the "true" (cumulative daily) rainfall. The "monthly" gauge at Barakula was initialized to 20 millimetres each month to allow determination of evaporation in the absence of rainfall.

3. Analysis and Results

This investigation attempts to reveal the typical growth pattern of cypress pine throughout the year. In order to determine this, two options are available:

- It can be assumed that the rainfall pattern during the years 1974 to 1979 was typical of the long term average pattern, or

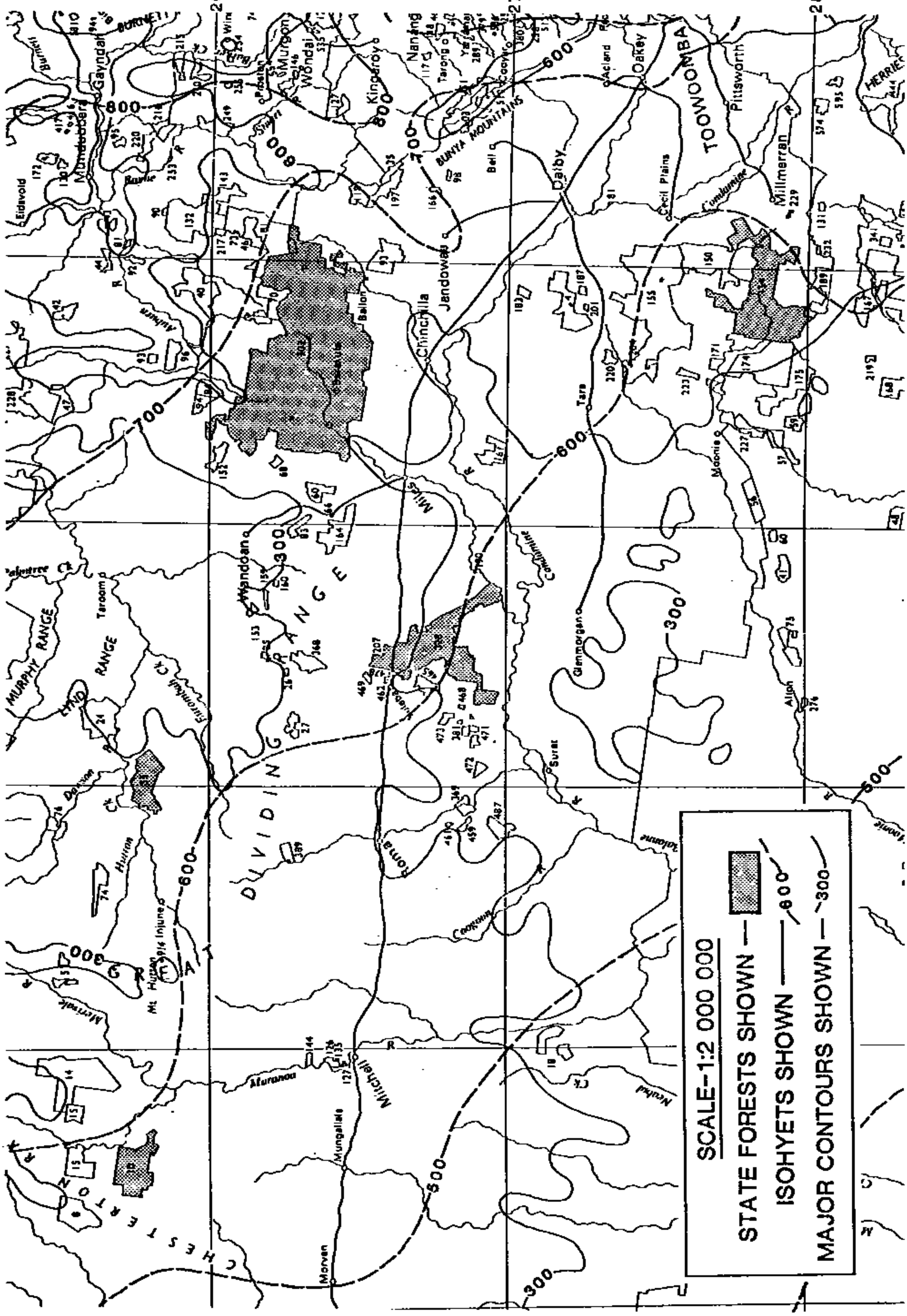


FIGURE 6. LOCATIONS OF MEASURED STEMS.

- The actual observed rainfall may be used in the analysis as a regressor (or so-called "independent") variable to describe the growth pattern, and the typical growth pattern may be surmised using long term average rainfall observations.

The nature of the rainfall observations in this experiment are not suitable for the second of these options, and it is necessary to make the former assumption. It is expedient to make a further assumption:

- That tree height and diameter increase monotonically. That is, height and diameter increments (adjusted for reversible stem swelling and shrinking) can never be negative, and must always be positive or zero.

Linear regression cannot be used for this analysis. The serial nature of these data (repeated measurements of the same stems) violates the assumption of independent residuals implicit in linear regression. Thus non-linear regression must be used.

3.1 **Rainfall**

Regression analysis indicated that a straight line relationship existed between observations on the paired gauges; that the slope of this line was not significantly different from unity; and that the intercept was strongly influenced by month of the year. This implies that the monthly gauge faithfully recorded the rainfall, but lost water at a rate given by

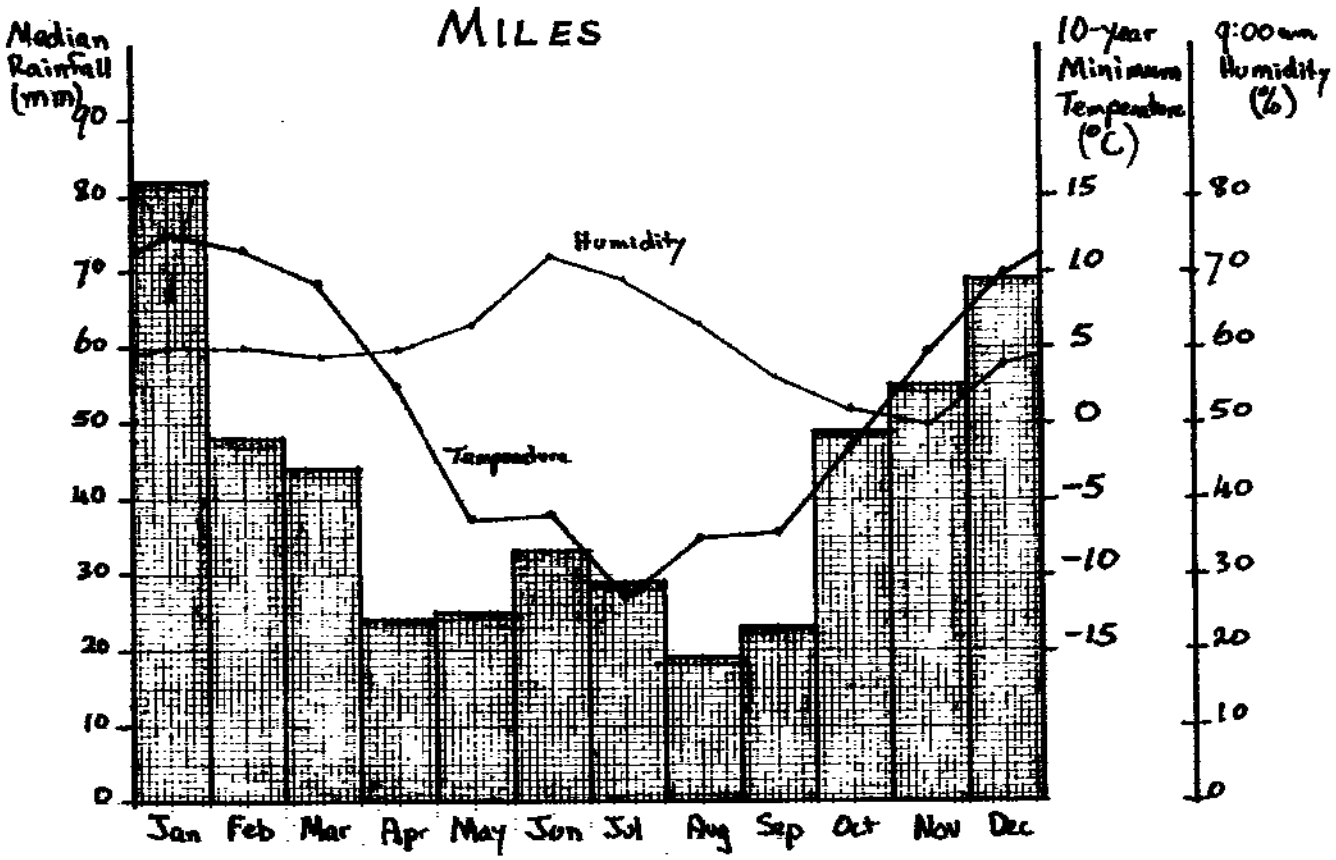
    Evap.Loss = {5.383+1.759Sin[Pi*(month+2.25)/6]}**2

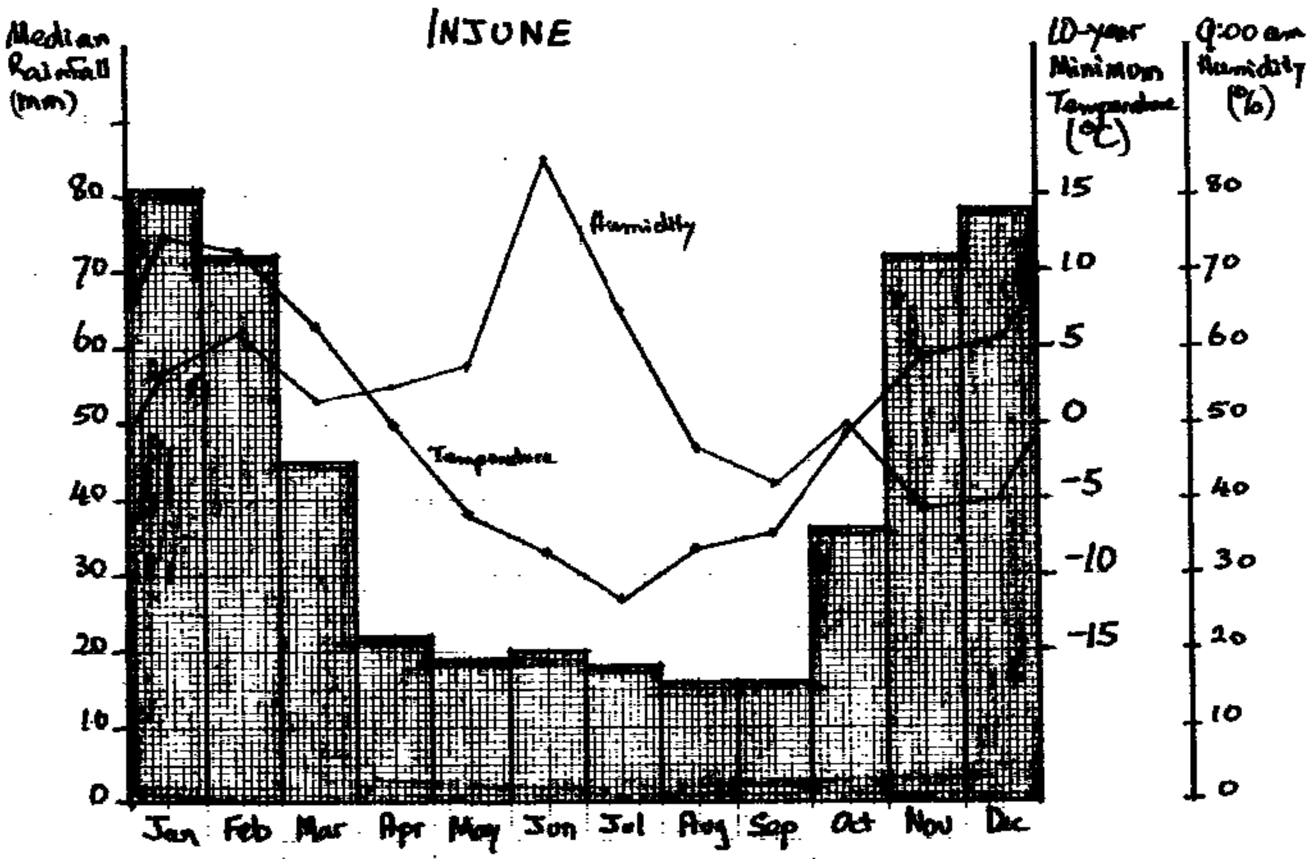
Thus loss from a monthly rain gauge may vary from 13 (July) to 51 (January) millimetres per month. As this loss is of the same order of magnitude as the rainfall in this region (Figure 7), the presence or absence of water in the gauge is not considered to be a reliable indicator of rainfall. For example, some water in the gauge may indicate heavy rain early in the month followed by fine weather, or a dry month with a light shower the previous day. Thus the volume of water in the gauge is useful only as an general indicator of soil moisture content and stem hydration.

3.2 **Height Growth**

The height observations conform well to the assumption of monotonic increasing height, with only one exception. In November 1976, the height of tree 257 suddenly decreased to c. 11.4 metres after several months at c. 11.7 metres, and continued to remain at this lesser height. To enable a

Figure 7.


MILES
Median Rainfall (mm)
10-year Minimum Temperature (°C)
9:00 am Humidity (%)
Humidity
Temperature
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


INJUNE
Median Rainfall (mm)
10-year Minimum Temperature (°C)
9:00 am Humidity (%)
Humidity
Temperature
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

feasible model to be applied to these data, it was assumed that the tip had broken.

The non-linear model proposed was

$$H(i,j) = H(i,j-1) + r(i)*m(j') - b$$

where H(i,j) is the height of tree i at the end of month j, H(i,0) is the initial height of tree i, r(i) is the average annual height increment for tree i, m(j) is the proportion of the annual increment occurring during month j', j' is the month of the year corresponding to month j, and b is the breakage and is zero for all trees and months except for tree 257 in November 1976.

This model implies the following assumptions:

- height increases monotonically (increments may be positive or zero, but never negative);
- each tree has its own unique annual increment rate, and maintains this increment during each of the five years of observation; and
- the proportion of the annual increment accruing in any month is the same for all trees.

The estimated monthly increments are given in Figure 8. Annual height increments varied from 13.2 cm for a tree 11.4 m high to 40.1 cm for a 7.5 m tree. The estimated breakage was 36 cm, and the standard error of height estimates was 8.3 cm.

The results of this analysis exhibited some resemblance to a sine curve, and a refined model was proposed:

$$P(j)=\{c+Sin[(j+d)*2*Pi/365]\}/365$$

where P(j) is the proportion of the annual increment occurring on day j, d determines when during the year the greatest and least increments occur, and c determines the amount of increment occurring on the day of least increment.

This analysis yielded similar estimates for initial heights, height increments and the breakage. Parameter c was estimated as exactly 1.0, and parameter d as 52.5. This predicts a zero height increment on 9 August, and the maximum increment on 8 February. The standard error of height estimates was 9.1 cm.

The predicted growth pattern suggests that height growth may cease during the months July to September. Examination of climatic data for the region (Anon. 1975) revealed that the monthly minimum temperature followed a similar trend. The weather in late winter is more variable than in early

FIGURE 8. HEIGHT INCREMENT DISTRIBUTION.

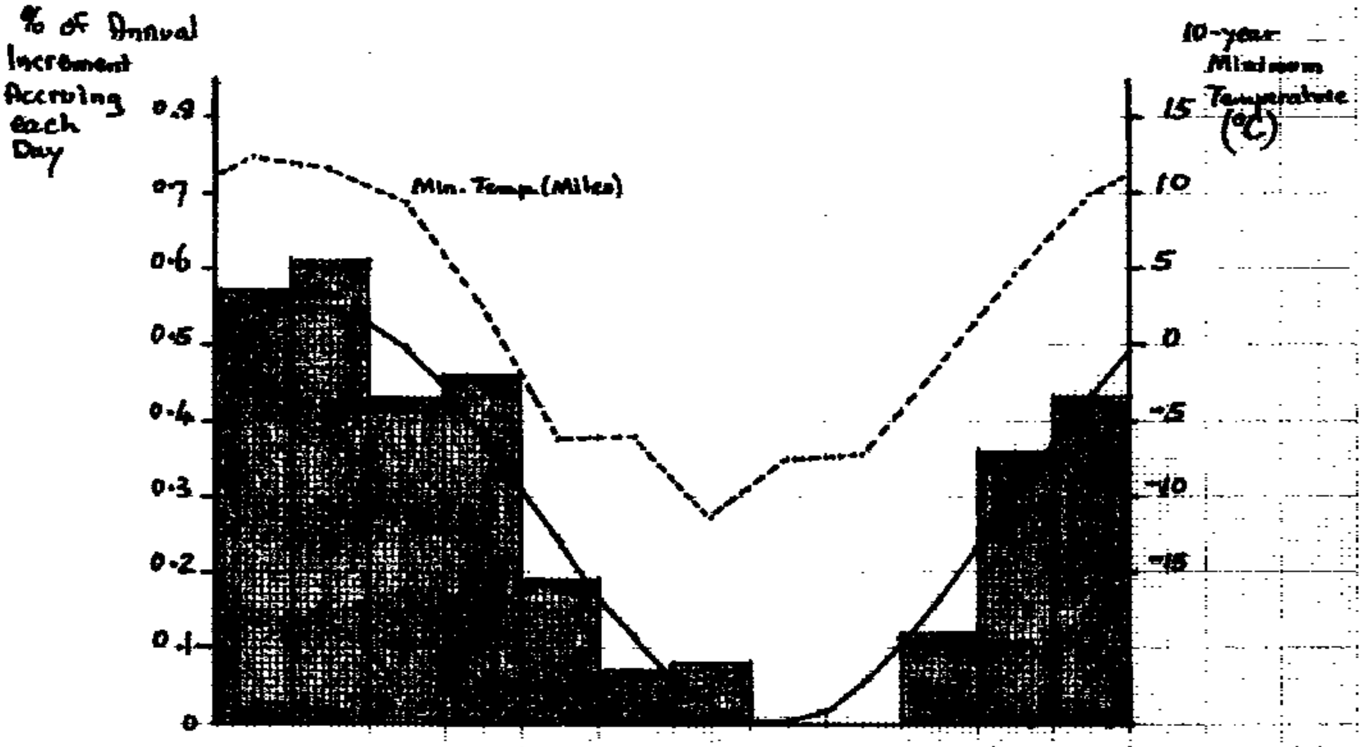
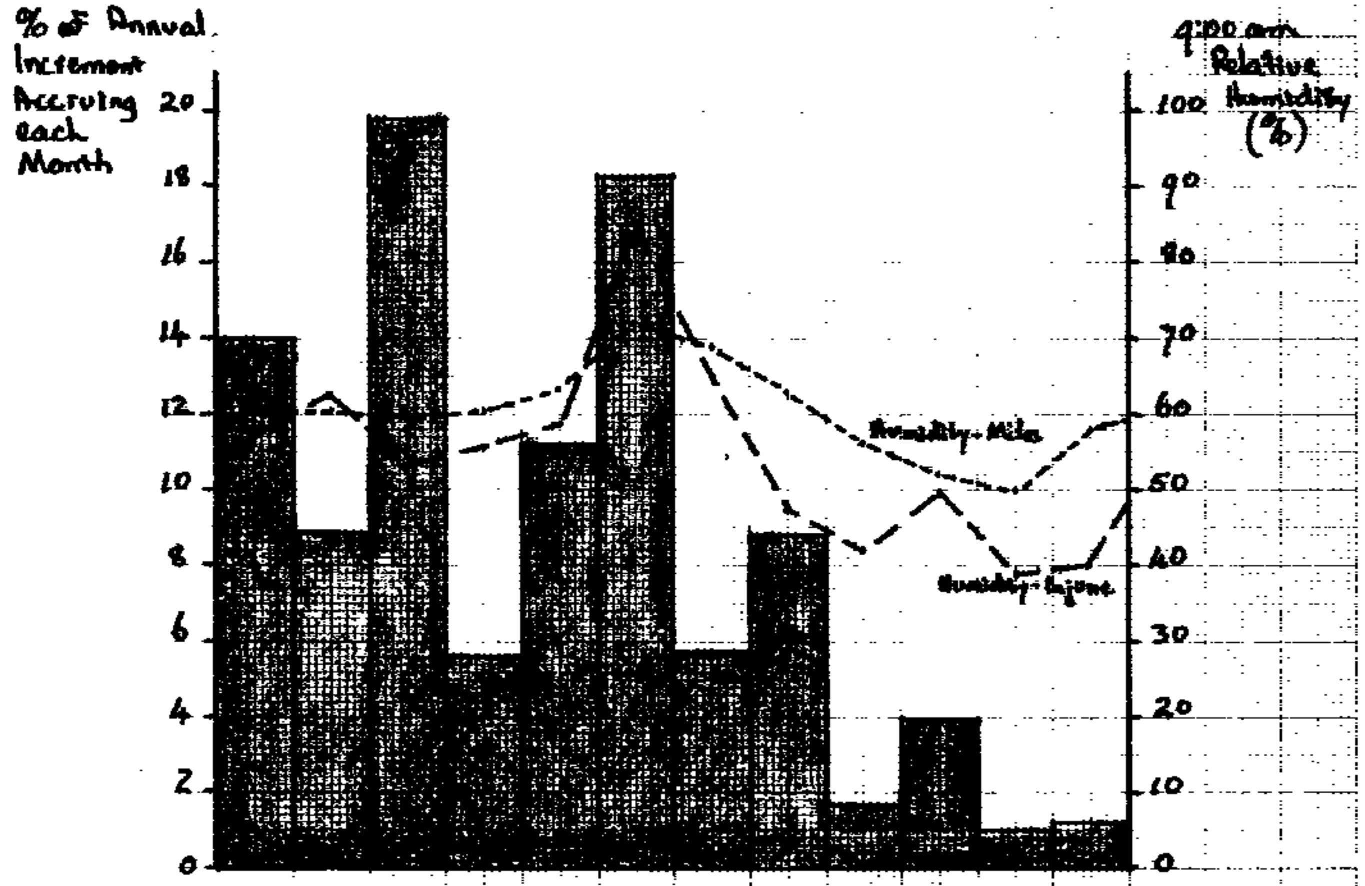


FIGURE 10. DIAMETER INCREMENT DISTRIBUTION



winter, and the chance of frost is correspondingly greater. The ten-year minimum temperature† reflects this lag, and corresponds closely with the height growth pattern.

3.3 Daily Diameter Observations

A more complex model is required for the diameter observations, as these do not increase monotonically as with height, but show considerable variation. Figure 9 illustrates the fluctuating nature of diameter, and the dramatic response to rainfall. Johnston (1978 p.84) attributes these reversible changes in stem diameter to bark swelling and shrinking with changing moisture content. M.R. Nester (pers. comm.) is conducting an analysis of this phenomenon, and proposes that:

- Following rain, the bark immediately swells (by an amount linearly related to rainfall, up to its maximum swelling), then gradually shrinks as an exponential decay as it dries.

- Irreversible diameter growth is also linearly related to rainfall, but occurs more gradually over the following thirty day period.

The rapid increase in stem diameter following rain may be due to changes in either (or both) xylem or bark thickness. Odin (1972) found that wetting of Scots pine and Norway spruce bark had relatively little effect on stem size. Both seasonal and diurnal stem shrinkage of forest trees are well documented (Kozlowski 1982). Worrall (1966) demonstrates a linear relationship between stem diameter and water stress in <u>Callitris cupressiformis</u>, and Kozlowski and Winget (1964) showed substantial swelling of droughted poplar stems within 30 minutes of rainfall.

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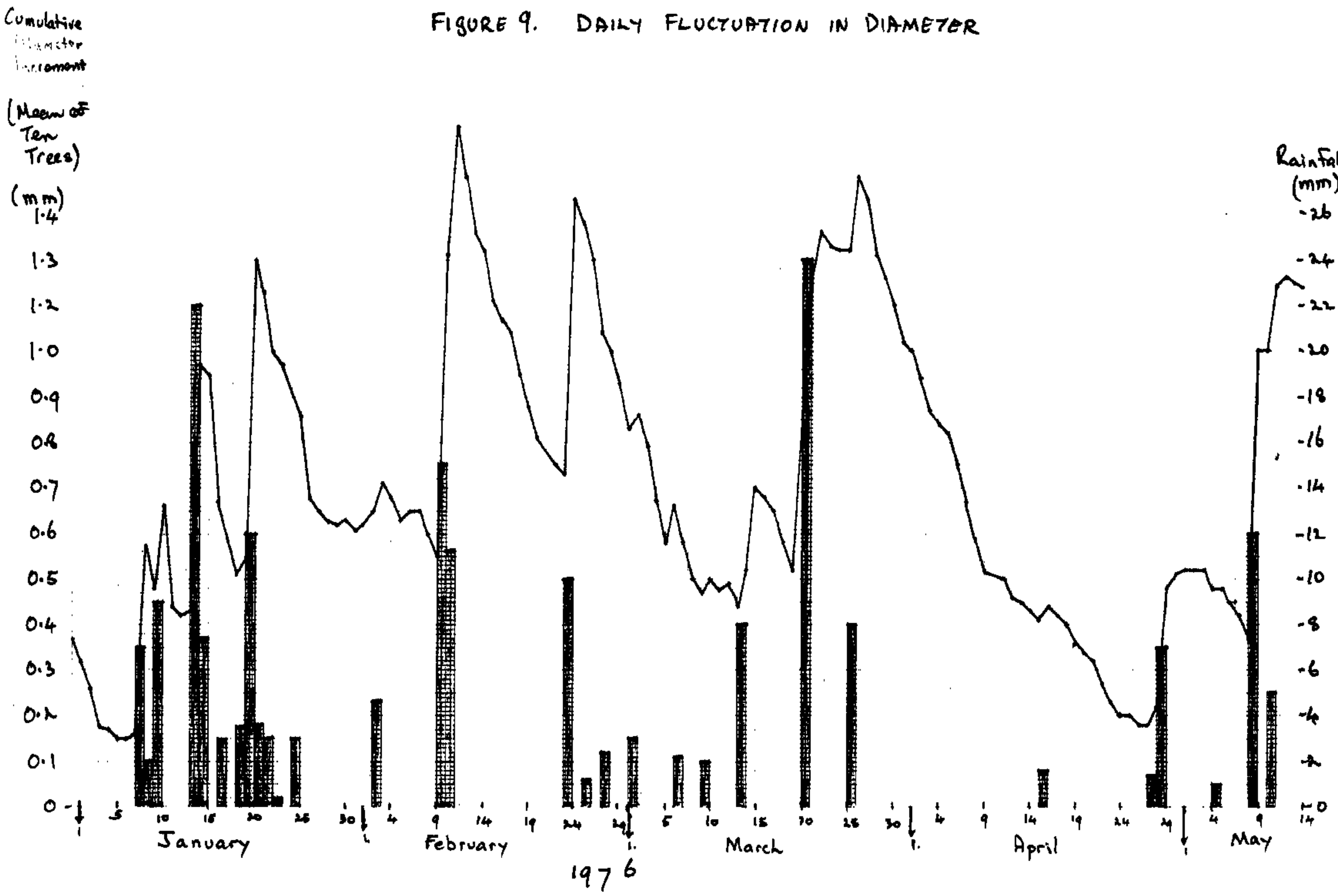
† This is computed as

10-yr-min = Mean - 2.52*(Mean-14Decile)

and represents the lowest temperature likely to be encountered during that month over a ten year period. Mean and 14Decile observations were derived from Anon (1975).

FIGURE 9. DAILY FLUCTUATION IN DIAMETER



3.4 Monthly Diameter Observations

The monthly diameter observations exhibited considerable fluctuation, presumably a result of seasonal and diurnal stem shrinkage. Regrettably, no account can be taken of diurnal shrinkage as time of measurement was not recorded. Some account may be taken of seasonal shrinkage by employing the rain gauge data.

The model proposed was

$$D(i,j) = D(i,j-1) + r(i)*m(j') + b(k)$$
$$D'(i,j) = D(i,j) * (1 + s*\mathrm{Min}[p(j),\mathrm{Pmax}])$$

where D(i,j) is the "dry diameter" of tree i at the end of month j, D'(i,j) is the corresponding observed diameter (including an allowance for any stem swelling), r(i) and m(j') are as above, b(k) allows for re-adjustment of the dendrometer band after damage by cattle, etc, s is the amount of stem swelling corresponding to a unit of water in the gauge, p(j) is the amount of water in the gauge at the end of month j, and Pmax represents the amount of water in the gauge corresponding to stem saturation.

This model implies the same assumptions as the model for height increment, and also implies that:

- the presence of water in the rain gauge indicates a degree of stem swelling correlated with the amount of water in the gauge.

The model is more compatible with the assumption of bark swelling than of seasonal shrinkage of the xylem, but is an efficient way of employing the available rain gauge data to account for some variation in the data. A more sophisticated attempt to model xylem shrinkage would require estimates of soil moisture content.

Changes in stem diameter conformed well to these assumptions, except for one small stem which violated the assumption of a constant average annual increment. This stem (tree 609, dbh 4.3 cm) at Western Creek exhibited a high increment for the first eighteen months followed by a very low increment, and was excluded from further analysis.

The results of this analysis are summarized in Tables 1, 2 and 3. Table 1 indicates the precision of the estimates, and the apparent relationship between stem swelling and the monthly gauge reading. The entry labelled "Saturation Level" refers to the amount of water in the gauge (at time of reading) which corresponds to maximum stem swelling, and not to the actual rainfall.

TABLE 1. Details of Analysis

Location	Stem Swelling (%/mm)	Saturation Level (mm)	Standard Error (mm dbh)	Degrees of Freedom
SF 10 Hillside	0.026	15	0.815	1212
SF 55 Pony Hills	0.003	55	0.716	977
SF 328 Yuleba	0.008	90	0.798	1364
SF 302 Barakula	0.005	22	0.636	1404
SF 154 Western Ck	0.024	2	1.127	2469

The estimated saturation level and rate of stem swelling varies considerably with location (Table 1). This may be due in part, to the placement of the rain gauge with respect to surrounding trees. This could influence both the accuracy with which the gauge records rainfall, and the rate of evaporation from the gauge.

Table 2 indicates the proportion of the annual increment accruing each month (standardized to 30-day months), and Table 3 indicates the estimated average annual increments.

Diameter growth does not exhibit the same regular pattern of height growth, but may occur at any time when conditions are favourable. The averaged figures (Table 2) indicate that the majority of diameter increment occurs during the first eight months of the year (January to August), and that very little increment occurs during the last four months. However, growth may cease at any time during the early part, or re-commence at any time during the later part of the year as conditions dictate. It is noteworthy that the average monthly increments correspond closely to the average 9:00 am humidity (Figure 10).

4. Discussion

The results of this analysis need to be interpreted with some caution. It is unreasonable to expect heights to be correctly measured to the nearest centimetre (Nester 1981), and it is not possible to completely distinguish irreversible growth from seasonal and diurnal stem shrinkage and swelling. This constant shrinking and swelling led Fielding and Millet (1941) to conclude that they could not determine by use of dendrometers when cambial activity in *Pinus radiata* began or ended. However, the analysis does yield some useful results.

TABLE 2. Relative Diameter Increment by Month

Location	Percent of Average Annual Increment occurring each Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SF 10 Hillside	15	9	17	19	0	17	0	15	3	0	0	5
SF 55 Pony Hills	21	0	23	8	0	10	27	6	4	0	0	0
SF 328 Yuleba	0	15	17	1	34	33	0	0	0	0	0	0
SF 302 Barakula	19	12	16	0	16	11	1	14	0	7	5	1
SF 154 Western Ck	15	8	27	0	7	20	0	9	2	12	0	0
Average	14	9	20	6	11	18	6	9	2	4	1	1

TABLE 3. Average Annual Increments

Location	Average all Stems			Best Stem Only		
	10 cm dbh (mm/ann)	20 cm dbh (mm/ann)	30 cm dbh (mm/ann)	10 cm dbh (mm/ann)	20 cm dbh (mm/ann)	30 cm dbh (mm/ann)
SF 10 Hillside	5.8	4.1	4.2	9.4	9.1	7.2
SF 55 Pony Hills	2.0	2.5	1.4	5.8	5.8	2.1
SF 328 Yuleba	2.1	1.7	1.6	3.2	2.5	2.5
SF 302 Barakula	2.9	3.1	2.8	6.1	4.9	4.5
SF 154 Western Ck	5.0	3.4	3.8	7.9	5.3	5.7

Height increments appear to exhibit a regular pattern with a dormant period of up to three months during July to September. The regular pattern suggests internal (hormonal) control of growth, and the pattern appears suited to protect the growing shoot from frost damage (Figure 8). This pattern is characteristic of shoot growth in temperate zones (Kozlowski 1982).

The swelling and shrinking of the stem (Table 1 and Figure 9) may attain a magnitude equivalent to the annual increment (Table 3), and this poses difficulties in detecting and measuring irreversible increment. The adopted model expresses stem swelling as a simple linear function of the water level in the gauge, which may provide a reasonable estimate of moisture content of the bark, but is unlikely to reflect the soil moisture content. Lassoie (1979) found that stem shrinkage was linearly related to recent growth, and argued that these newly formed tissues formed major water storage areas within the plant. The current model expressed stem swelling as a proportion of stem size, not as a proportion of recent increment. However, the correlation between stem swelling (Table 1) and average annual increments (Table 2) suggests that Lassoie's (1979) contention may be more appropriate.

Diameter increment is more variable than height increment and appears to occur whenever favourable conditions occur. There is no suggestion of dormancy in winter (Figure 10); presumably there is no advantage in such dormancy as the cambium is well insulated against the mild frosts experienced in this region. This is consistent with research findings that apical growth is under stronger hormonal control than cambial growth (Kozlowski 1971a p.372).

The similar patterns of average increment and average 9:00 am humidity suggest that relative humidity may be a causal agent in determining the growth pattern of cypress pine. It is likely that during periods of low morning humidity (and high temperatures and strong winds) the rate of water depletion from the foliage exceeds the ability of the roots to replace the water, resulting in cessation of photosynthesis because of internal water deficits (Kozlowski 1971b p.131). Lassoie (1979) concluded that summer growth of Douglas fir was controlled by evaporative demand, rather than soil moisture content <u>per se</u>. Kozlowski (1982) also stresses that plant water deficits depend on relative rates of absorption and transpiration, and not on absorption alone.

Johnston (1975 p.51) observes that cypress pine stems in the understorey (of uneven-aged stands) grow very efficiently, apparently with minimal impact on overstorey increment. The above hypothesis offers some feasible explanation of this phenomenon. Humidity, temperature and windspeed are likely to be more favourable in the understorey, and could allow continuing photosynthesis in the understorey when water deficits have become limiting in the overstorey.

5. Conclusion

Three important conclusions may be drawn from this study:

- There is some evidence to suggest that height growth exhibits a period of dormancy during July to September.
- Diameter growth appears not to enter a dormant state, but occurs whenever conditions (soil moisture status and rate of water loss from foliage) are suitable to sustain growth.
- The natural variation in stem diameter (due to changing moisture status) may exceed the annual diameter increment.

The implications of these conclusions for model development are:

- Diameter increments should be based on a time interval of not less than two years.
- When calculated from measurements corresponding to time intervals not an exact multiple of one year, diameter increment should be assumed to be constant throughout the year.

6. Acknowledgements

Experiment 163 Dalby was initiated by T.N. Johnston, and has involved numerous officers of Forest Research Branch. Special recognition is made of the work of J. Macalister in the daily measurement of stems. Dr. G. Bacon contributed valuable criticism of an earlier draft.

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